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DERIVING ALLOWABLE PROPERTIES OF LUMBER (A PRACTICAL GUIDE FOR --ETC(U)
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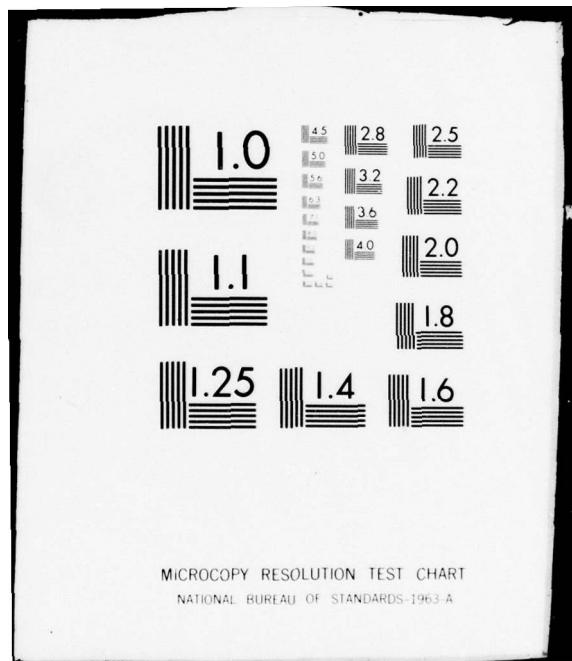
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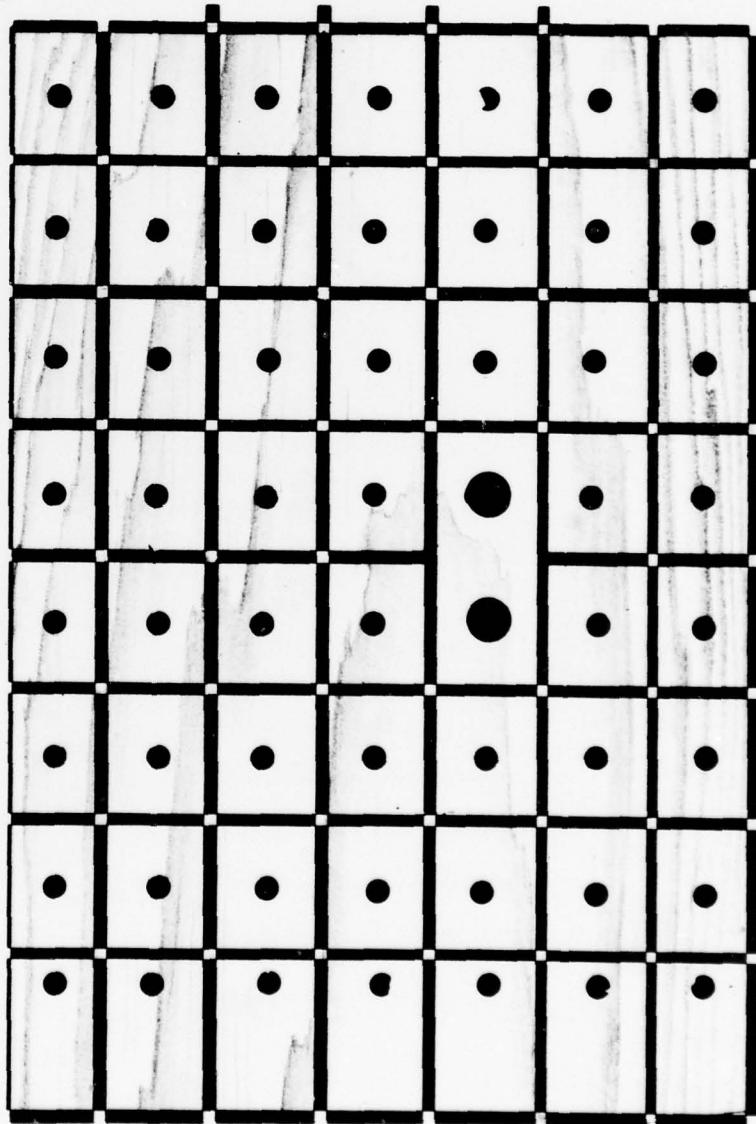
*(A Practical Guide for
Interpretation of ASTM
Standards)*

General
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Forest Products Laboratory
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ABSTRACT

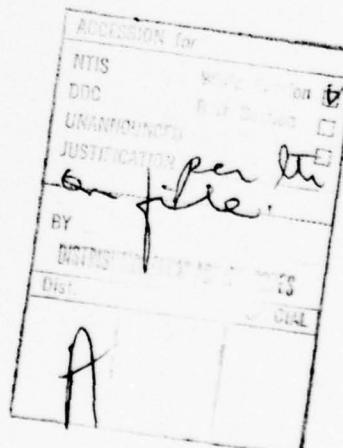
✓ The ASTM standards for establishing clear wood mechanical properties and for deriving structural grades and related allowable properties for visually graded lumber can be confusing and difficult for the uninitiated to interpret. This report provides a practical guide to using these standards for individuals not familiar with their application. Sample stress derivations are presented to supplement the text.

A

B

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PREFACE

Allowable properties are assigned to lumber to achieve proper recognition of structural capability and to provide for uniformity in design application. The long tradition of successful structural use of lumber in the United States is based on an orderly development of key national standards for both grading and assignment of properties to grades.

The assignment of properties to visually graded lumber follows precepts developed by technical personnel in lumber research and manufacture. Since 1927, these have been recorded as standards of the American Society for Testing and Materials (ASTM). The most common use of the standards is by grading agencies preparing grading rules and grade descriptions for approval under the American Lumber Standard (PS 20-70). The procedures have other users, however, including consultants, research laboratories, and universities. While the lumber rules-writing agencies have extensive experience with these documents, the more uninitiated user often finds some frustration in the somewhat tortuous path one must follow through the procedures. This report takes the user step by step through the procedures in the sequence and manner in which these standards are commonly interpreted.

6 DERIVING ALLOWABLE PROPERTIES OF LUMBER

(A Practical Guide for Interpretation of ASTM Standards),

By

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INTRODUCTION

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The visual lumber grading system employed in the United States and Canada is based on two key ASTM Standards, ASTM D 2555-76, "Standard Methods for Establishing Clear Wood Strength Values" (3)^{2/} and ASTM D 245-74, "Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber" (2). These standards function in sequence, with clear wood properties cataloged and grouped by D 2555 and the adjustments for design derived from D 245.

These ASTM standards are equally applicable to hardwoods and to softwoods, although they have been applied much more generally to softwoods. This report was prepared as a part of a cooperative effort with the National Bureau of Standards, in which hardwoods for trenching were the target. Consequently, the examples in this report employ hardwood data.

In application of D 245 under American Lumber Standard PS 20-70 (7), lumber nominally 2 to 4 inches thick (termed "dimension") is governed by the National Grading Rule, a document that standardizes many features of lumber grading across the United States. One feature that must be followed uniformly between agencies is the minimum strength ratio in bending applicable to a grade. Strength ratios for other properties also are consistent because the National Grading Rule also specifies knots and other characteristics permitted in dimension lumber.

1/ Maintained at Madison, Wis. in cooperation with the University of Wisconsin.

2/ Underlined numbers in parentheses refer to publications in the Bibliography near the end of this report.

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It is recognized that this report does not cover all possible aspects of the derivation process. (In fact, the ASTM standards also fail to do that.) When these procedures become "institutionalized" through repetitive use by a lumber rules-writing agency, key decisions must be made that relate practical concerns for uniformity and standardization to the procedures permitted by ASTM. For example, the strength ratios used by agencies for specific lumber grade-size combinations sometimes exceed those nominally assigned to a grade because the critical defect (for uniformity or efficiency) is more limiting (smaller) than required by the National Grading Rule (see appendix C).

There are no specific strength ratio requirements under PS 20-70 for sizes other than dimension. Consequently, a grade of timber (Beams and Stringers or Posts and Timbers) defined by one grading agency may differ slightly from that of another. In southern pine, for example, timber is graded uniformly along the length; by contrast, some western timber has particular restrictions on the middle third of the piece, corresponding to the presumed region of maximum bending moment in end use. Such differences are permitted under PS 20-70. Similar interpretations of ASTM standards are important, but all cannot be chronicled here. This report emphasizes standard procedures and interpretations.

DERIVATION OF ALLOWABLE PROPERTIES

Allowable properties for visually graded lumber are based on clear wood properties as cataloged in D 2555 (3). D 2555 also provides rules and procedures for developing clear wood properties of species grouped for marketing purposes. Once clear wood properties of a species or market group are established, the steps necessary for allowable property derivation are found in D 245.

Several sample property derivations (tables 1-10) illustrate application of these standards. Yellow-poplar demonstrates the derivation of stresses for a single species; the "aspen" group demonstrates a combination (marketing group) where the composite dispersion factor (CDF) for the group is not limiting; the "maple" group illustrates a combination for which the CDF is controlling; and "cottonwood" illustrates a combination involving both a method A and a method B species. The aspen, maple, and cottonwood groupings are not intended as official marketing groups but were selected arbitrarily to illustrate various possible combination procedures.

For accurate identification of species both common and botanical names are included here:

| | | |
|-------------------|---|--------------------------------|
| Aspen, bigtooth | - | <u>Populus grandidentata</u> |
| quaking | - | <u>P. tremuloides</u> |
| Cottonwood, black | - | <u>P. trichocarpa</u> |
| eastern | - | <u>P. deltoides</u> |
| Maple, black | - | <u>Acer nigrum</u> |
| red | - | <u>A. rubrum</u> |
| silver | - | <u>A. saccharinum</u> |
| sugar | - | <u>A. saccharum</u> |
| Yellow-poplar | - | <u>Liriodendron tulipifera</u> |

Basic Clear Mechanical Property

Statistics and Timber Volume Estimates

Table 1 lists the average, standard deviation, and variability index obtained by double sampling (method A species) for mechanical properties of black cottonwood. (Table 1 of D 2555 is the data source for method A species.) Currently, 12 softwood species and one hardwood (black cottonwood) have been evaluated by double sampling.

Averages and standard deviations for method B species are also listed in table 1. Method B species are those for which mechanical property estimates are established in accordance with D 143 or by random sampling procedures. (Tables 2 and 3 of D 2555 are the data sources for method B species.)

Standing timber volume estimates are also listed in table 1. (Tables 4 and 5 of D 2555 are the primary data sources for volume data.) Volume data have been collected for some hardwood species not included in D 2555 and are tabulated in appendix A.

Species Combinations and Weighting Factors

It is frequently desirable for marketing purposes to combine or group species that have relatively similar properties. ASTM procedures seek equitable treatment for each species in a group or combination by weighting factors based upon standing timber volume. A species weighting factor is the ratio of individual species volume to the combined volume of all species in the combination (D 2555, par. 5). Examples of marketing groups, species, and weighting factors are listed in table 2.

Table 1.--Clear wood mechanical property means and measures of variability and timber volume

| Species or region | Modulus of rupture | | | Modulus of elasticity | | | Compression parallel | | | Shear | | | Compression perpendicular | | | Volume ft. ³ |
|-------------------------|--------------------------------|---------------|-----------------------|--------------------------------|---------------|-----------------------|--------------------------------|---------------|-----------------------|--------------------------------|---------------|-----------------------|--------------------------------|---------------|-----|----------------------------|
| | Average Lb/in. ² | Var. index | Standard deviation | Average Lb/in. ² | Var. index | | |
| | | | | | | | | | | | | | | | | |
| METHOD A SPECIES | | | | | | | | | | | | | | | | |
| Cottonwood, black | 4,890 | 1.00 | 951 | 1,083 | 1.00 | 197 | 2,200 | 1.00 | 360 | 612 | 1.00 | 92 | 165 | 46 | 394 | |
| METHOD B SPECIES | | | | | | | | | | | | | | | | |
| Aspen | | | | | | | | | | | | | | | | |
| Birch | 5,400 | 864 | 1,120 | 246 | 450 | 732 | 102 | 206 | 58 | | | | | | | |
| Quaking | 5,130 | 821 | 860 | 189 | 2,140 | 556 | 92 | 181 | 51 | | | | | | | |
| Maple | | | | | | | | | | | | | | | | |
| Black | 7,920 | 1,267 | 1,328 | 292 | 3,270 | 589 | 1,128 | 158 | 601 | 168 | 1,801 | | | | | |
| Red | 7,690 | 1,230 | 1,386 | 305 | 3,280 | 590 | 1,151 | 161 | 405 | 113 | 6,037 | | | | | |
| Silver | 5,820 | 931 | 943 | 207 | 2,490 | 448 | 1,053 | 147 | 369 | 103 | 5,507 | | | | | |
| Sugar | 9,420 | 1,507 | 1,546 | 340 | 4,020 | 724 | 1,465 | 205 | 645 | 181 | 8,566 | | | | | |
| Yellow- poplar | 5,950 | 952 | 1,222 | 269 | 2,660 | 479 | 792 | 111 | 269 | 75 | 6,753 | | | | | |
| Cottonwood, Eastern | 5,260 | 842 | 1,013 | 223 | 2,280 | 410 | 682 | 95 | 196 | 55 | 1/5,000 | | | | | |

1/ Timber volume estimates for eastern cottonwood are not available. A fictitious estimate is assumed in order to demonstrate species combinations and property derivation procedures in subsequent tables.

Table 2.--Combinations and combination weighting factors

| Combination | Species | Volume | Weighting factor |
|-------------------------------|----------|--------|------------------|
| <u>Million ft³</u> | | | |
| Aspen | Bigtooth | 2,970 | 0.2112 |
| | Quaking | 11,093 | .7888 |
| Maple | Black | 1,801 | .0822 |
| | Red | 6,037 | .2755 |
| | Silver | 5,507 | .2513 |
| | Sugar | 8,566 | .3909 |
| Cottonwood | Black | 394 | .0730 |
| | Eastern | 5,000 | .9270 |

Clear Wood Stresses

This section shows how stresses are assigned for clear, unseasoned wood for individual species and for marketing groups. Modulus of rupture, compression parallel to grain ($C_{||}$), and shear strength are near minimum property values (5 pct exclusion limits); compression perpendicular to grain (C_{\perp}) and modulus of elasticity (E) are average values. Tables 3 to 6 summarize procedures for assigning clear wood stresses. Further application of procedures for assigning clear wood values to combinations as outlined below and in tables 3 to 6 are given in D 2555, 5.5.

Exclusion Limits

Exclusion limits (EL) for individual species are calculated as

$$EL = \bar{x} - 1.645 s \text{ (Note 9, D 2555)}$$

where \bar{x} and s are estimates of species averages and standard deviations from table 1.

Table 3.--Assigned exclusion limits for modulus of rupture,
compression parallel, and shear (lb/in.²)

| Species or combination | Species | \bar{x} | VI | s | Exclusion limit or weighted exclusion limit | CDF | CDF check value | Assigned value |
|------------------------|----------|-----------|------|-------|---|------|-----------------|----------------|
| MODULUS OF RUPTURE | | | | | | | | |
| Aspen | Bigtooth | 5,400 | | 864 | 3,814 | 1.84 | NA | 3,814 |
| | Quaking | 5,130 | | 821 | | 1.60 | | |
| Maple | Black | 7,920 | | 1,267 | | 2.33 | | |
| | Red | 7,690 | | 1,230 | | 2.22 | | |
| | Silver | 5,820 | | 931 | 4,963 | .92 | 4,442 | 4,442 |
| | Sugar | 9,420 | | 1,507 | | 2.96 | | |
| Yellow-poplar | | 5,950 | | 952 | 4,384 | | | 4,384 |
| Cottonwood | Black | 4,890 | 1.00 | 951 | 3,820 | 1.13 | 3,768 | 3,768 |
| | Eastern | 5,260 | | 842 | | 1.71 | | |
| COMPRESSION PARALLEL | | | | | | | | |
| Aspen | Bigtooth | 2,500 | | 450 | 1,538 | 2.14 | NA | 1,538 |
| | Quaking | 2,140 | | 385 | | 1.56 | | |
| Maple | Black | 3,270 | | 589 | | 2.0 | | |
| | Red | 3,280 | | 590 | | 2.07 | | |
| | Silver | 2,490 | | 448 | 2,056 | .97 | 1,827 | 1,827 |
| | Sugar | 4,020 | | 724 | | 2.71 | | |
| Yellow-poplar | | 2,660 | | 479 | 1,872 | | | 1,872 |
| Cottonwood | Black | 2,200 | 1.00 | 360 | 1,606 | 1.65 | NA | 1,606 |
| | Eastern | 2,280 | | 410 | | 1.64 | | |
| SHEAR | | | | | | | | |
| Asper | Bigtooth | 732 | | 102 | 512 | 2.15 | NA | 512 |
| | Quaking | 656 | | 92 | | 1.56 | | |
| Maple | Black | 1,128 | | 158 | | 1.55 | | |
| | Red | 1,151 | | 161 | | 1.67 | | |
| | Silver | 1,053 | | 147 | 883 | 1.16 | 835 | 835 |
| | Sugar | 1,465 | | 205 | | 2.84 | | |
| Yellow-poplar | | 792 | | 111 | 609 | | | 609 |
| Cottonwood | Black | 612 | 1.00 | 92 | 518 | 1.02 | 503 | 503 |
| | Eastern | 682 | | 95 | | 1.73 | | |

Table 4.--Assigned averages for compression perpendicular (lb/in.²)

| Species or combination | Species | \bar{x} | Weighting factor | Weighted \bar{x} | Check value ($\bar{x}_{\min} \cdot 1.10$) | Assigned value |
|------------------------|----------|-----------|------------------|--------------------|---|----------------|
| Aspen | Bigtooth | 206 | 0.2112 | | | |
| | Quaking | 181 | .7888 | 186.3 | 199.1 | 186 |
| Maple | Black | 601 | .0822 | | | |
| | Red | 405 | .2755 | | | |
| | Silver | 369 | .2513 | 505.8 | 405.9 | 406 |
| | Sugar | 645 | .3909 | | | |
| Yellow-poplar | | 269 | NA | NA | NA | 269 |
| Cottonwood | Black | 165 | .0730 | | | |
| | Eastern | 196 | .9270 | 194 | 181.5 | 182 |

Exclusion limits for combinations are the 5th percentile of the volume-weighted frequency distribution (D 2555, 5.2.2.2 and 5.3.2.2). A computer program for computation of a group exclusion limit (GEL) is given in appendix B. However, an estimate can be obtained by computing a volume weighted average GEL for all species in the combination (D 2555, Note 8).

Method A species--(D 245, 5.2.2.3) GEL is limited by a composite dispersion factor (CDF) value of 1.18. CDF is calculated for each species in the combination as

$$CDF = \frac{(\bar{x}/VI) - GEL}{s} \quad (1)$$

where VI is the variability index from table 1. If CDF for one or more species in a combination is less than 1.18, the assigned value is the minimum GEL calculated as

$$GEL = (\bar{x}/VI) - 1.18 s \quad (2)$$

for each species having a CDF less than 1.18.

Table 5.--Assigned averages for modulus of elasticity (1,000 lb/in.²)

| Species or combination | Species | \bar{x} | Weighting factor | Weighted x | VI | \bar{x}/VI_{min} | Method A check ($1.16 \cdot \bar{x}/VI_{min}$) | Method B check ($\bar{x}_{min} \cdot 1.10$) | Assigned value |
|------------------------|----------|-----------|------------------|------------|------|--------------------|---|--|----------------|
| Aspen | Bigtooth | 1,120 | 0.2112 | | | | | | 915 |
| Maple | Quaking | 860 | .7888 | 914.9 | | | | 946.0 | |
| | Black | 1,328 | .0822 | | | | | | |
| | Red | 1,386 | .2775 | | | | | | |
| | Silver | 943 | .2513 | 1,335.1 | | | | 1,037.3 | 1,037 |
| Yellow-poplar | | 1,546 | .3909 | | | | | | |
| | | 1,222 | | | | | | | 1,222 |
| Cottonwood | Black | 1,083 | .0730 | 1,018 | 1.00 | 1,083 | 1,256 | | |
| | Eastern | 1,013 | .9270 | | | | | 1,114 | 1,018 |

Table 6.--A sample property derivation (E) when D 2555 tables A1 and A2 ratios are limiting^{1/}

| Species or combination | Green \bar{x} | Seasoning factor ^{2/} | \bar{x}_{19} or \bar{x}_{15} | Weighting factor | Weighted \bar{x}_{19} or \bar{x}_{15} | Method B check | Assigned value | Allowable unit stress for clear lumber ^{3/} |
|------------------------|---|--------------------------------|---|------------------|---|---|---|--|
| | <u>1,000</u> <u>lb/in.²</u> | | <u>1,000</u> <u>lb/in.²</u> | | <u>1,000</u> <u>lb/in.²</u> | <u>1,000</u> <u>lb/in.²</u> | <u>1,000</u> <u>lb/in.²</u> | <u>1,000</u> <u>lb/in.²</u> |
| 19 PERCENT MC | | | | | | | | |
| Black | 1,328 | 1.14 | 1,514 | 0.0822 | | | | |
| Red | 1,386 | 1.133 | 1,570 | .2755 | | | | |
| Silver | 943 | 1.14 | 1,075 | .2513 | 1,508 | 1,182 | 1,257 | |
| Sugar | 1,546 | 1.126 | 1,741 | .3909 | | | | |
| 15 PERCENT MC | | | | | | | | |
| Black | 1,328 | 1.20 | 1,594 | .0822 | | | | |
| Red | 1,386 | 1.19 | 1,649 | .2755 | | | | |
| Silver | 943 | 1.20 | 1,132 | .2513 | 1,582 | 1,245 | 1,324 | |
| Sugar | 1,546 | 1.18 | 1,824 | .3909 | | | | |

^{1/} This table applies only to modulus of elasticity because it is the lone instance in this paper where D 2555 table A1 or A2 ratios are limiting. The format of the table will vary depending upon whether method A or B species are used or which mechanical property is involved.

^{2/} The factor for 15 pct MC is the dry/green ratio (D 2555, table A-1) limited by the seasoning factor (D 245, table 11); for 19 pct MC the factor is calculated from the 15 pct MC factor according to D 245, 7.1.2 and is also limited by the seasoning factor (D 245, table 11).

^{3/} Assigned value ÷ 0.94. Enter in table 8.

Method B species.--(D 245, 5.3.2.3) GEL is limited by a CDF value of 1.48. CDF is calculated for each species in the combination as

$$CDF = (\bar{x} - GEL)/s \quad (3)$$

If CDF for one or more species in a combination is less than 1.48, the assigned value is the minimum GEL calculated as

$$GEL = \bar{x} - 1.48 s \quad (4)$$

for each species having a CDF less than 1.48.

Both A and B species.--CDF limits are applied to method A species as per equations (1) and (2); to method B species as per equations (3) and (4). If CDF limitations are involved, the lowest result of equations (2) and (4) is assumed for GEL (D 2555, 5.4.2.1).

Mean Values

C_L and E values for combinations are volume-weighted averages calculated as

$$\bar{x} = \sum_1^n R_i \bar{x}_i \quad (5)$$

where

\bar{x} = volume-weighted average for a combination,

n = number of species in the combination, and

R = ratio of the volume of the ith species to the combined volume of all species in the combination (D 2555, 5.2.1, 5.3.1, and 5.4.1)

\bar{x} = average C_L or E value of the ith species.

Method A species.--Assigned E values may not exceed the minimum quantity, 1.16 (\bar{x}/VI), calculated for each species (D 2555, 5.2.1.1, 5.2.2). C_L is limited as for method B species.

Method B species.--The assigned C_{\perp} and E values may not exceed the minimum quantity, $1.10 \bar{x}$, in the combination (D 2555, 5.3.1.1).

Both A and B species.--For combinations containing both method A and method B species, the limitations of method A and method B are applied as appropriate.

Nonvolume Species

A species for which no volume estimates are available may be included in a combination. Assigned values are determined for the combination excluding the "nonvolume" species and for the "nonvolume" species as an individual. If the assigned values for the "nonvolume" species exceed the combination values, the combination values are assumed. If not, the assigned values for the "nonvolume" species are assumed for the combination.

Clear Wood Property Summary

Table 7 summarizes the clear wood property assignments for individual species and marketing combinations as derived in tables 3 to 6. Modulus of rupture values are assumed for clear wood tension values.

Allowable Unit Stresses for Clear, Straight-Grained Lumber

Allowable unit stresses for clear straight-grained lumber are derived from the clear wood values in table 7 by adjustment factors and modifications for seasoning effects and density (in our examples, modification for density is not applicable). The result is shown in table 8.^{3/} F_b values apply to lumber 2 inches wide only.

Adjustment Factors (D 245, 6.2, 6.2.1, and table 9)

F_b , F_t , F_c , and F_v adjustment factors include a factor for normal duration of load and a factor of safety.

The factor for E adjusts for span-depth ratio from 14 to 21 and from concentrated centerpoint loading to uniform loading.

^{3/} Allowable properties are symbolized by the notation F_b for bending, F_t for tension, F_c for compression parallel, F_v for shear, $F_{C\perp}$ for compression perpendicular, and E for modulus of elasticity.

Table 7.--Clear wood values summary

| Species or combination | Modulus of rupture Lb/in.^2 | $C\parallel$ | Shear Lb/in.^2 | $C\perp$ | Modulus of elasticity $\frac{1,000}{\text{lb/in.}^2}$ |
|------------------------------|---|-------------------|----------------------------|-------------------|--|
| | | Lb/in.^2 | Lb/in.^2 | Lb/in.^2 | |
| Aspen | 3,814 | 1,538 | 512 | 186 | 915 |
| Maple | 4,442 | 1,827 | 835 | 406 | 1,037 |
| Yellow-poplar | 4,384 | 1,872 | 609 | 269 | 1,222 |
| Cottonwood | 3,768 | 1,606 | 503 | 182 | 1,018 |

The factor for $F_{C\perp}$ includes adjustment for average ring position and a factor of safety.

F_t is derived as $0.55 F_b$. (D 245, 4.2.5)

Seasoning Modifications (D 245, table 11)

Table 8 contains unseasoned values which apply to lumber of all dimensions, except for F_b values which apply to 2-inch depth only.

Allowable stresses, reflecting increases for 19 and 15 percent maximum moisture content in use, are also given in table 8. These increases for seasoning are limited by the Dry/Green clear wood property ratios in D 2555, tables A1 and A2.

Provisions for handling seasoning increases for instances where D 2555 ratios are limiting are given in D 245 (7.1.2) when stresses for a single species are being derived.

D 245 does not provide direction for handling seasoning increases when the D 2555 ratios are limiting for one or more species in a combination. However, the American Lumber Standards Committee (ALSC) Board of Review has approved a procedure that performs seasoning adjustments prior to forming a combination (WWPA Grading Rule, 3rd Edition effective July 1, 1974 (8)). Seasoning adjustments are made to the averages and standard deviations tabulated in table 1 for all species in the combination. For individual species or properties controlled by D 2555 ratios (tables A1 and A2), the adjustments are as per D 245 (7.1.2); other adjustments are as normal (D 245, table 11), except that the seasoning factor is applied to both the average and standard deviation. Using the adjusted values,

Table 8.--Allowable unit stresses for clear straight-grained lumber^{1/}

| Species or combination | $\frac{1}{F_b}$ | F_t | F_c | F_v | $F_{c\perp}$ | E |
|--|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|-------------------------------------|
| | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>1,000 lb/in.²</u> |
| UNSEASONED | | | | | | |
| Aspen | 1,658 | 912 | 732 | 114 | 124 | 973 |
| Maple | 1,931 | 1,062 | 870 | 186 | 271 | 1,103 |
| Yellow-poplar | 1,906 | 1,048 | 891 | 135 | 179 | 1,300 |
| Cottonwood | 1,638 | 901 | 765 | 112 | 121 | 1,083 |
| 19 PERCENT MAXIMUM MC | | | | | | |
| Aspen | 2,072 | 1,140 | 1,098 | 123 | 186 | ^{2/} 1,109 |
| Maple | 2,414 | 1,328 | 1,305 | 201 | 406 | ^{2/} 1,257 |
| Yellow-poplar | 2,382 | 1,310 | 1,336 | 146 | 268 | 1,482 |
| Cottonwood | 2,048 | 1,126 | 1,148 | 121 | 182 | 1,235 |
| 15 PERCENT MAXIMUM MC | | | | | | |
| Aspen | 2,238 | 1,231 | 1,281 | 129 | 186 | ^{2/} 1,168 |
| Maple | 2,607 | 1,434 | 1,522 | 210 | 406 | ^{2/} 1,324 |
| Yellow-poplar | 2,573 | 1,415 | 1,559 | 152 | 268 | 1,560 |
| Cottonwood | 2,211 | 1,216 | 1,339 | 127 | 182 | 1,300 |
| ^{3/} FOR SEASONED MATERIAL THICKER THAN 4 IN. | | | | | | |
| Aspen | | | 805 | | | 992 |
| Maple | | | 957 | | | 1,125 |
| Yellow-poplar | | | 980 | | | 1,326 |
| Cottonwood | | | 842 | | | 1,105 |

1/ F_b values apply to 2-inch depth only.

2/ Limited by dry-green ratio (table 6).

3/ F_b , F_t , F_v , and $F_{c\perp}$ are the same as for unseasoned.

combination and derivation procedures are carried out as usual beginning with moisture-adjusted table 1 values.^{4/}

For lumber sizes thicker than 4 inches, a 10 percent increase over green values is given for compression members and a 2 percent increase is given for modulus of elasticity (D 245, 7.1.3 and 7.1.4). Compression members must be sufficiently seasoned before the increase is applied, and appreciable seasoning of the outer fibers must take place to benefit from an increase in E. Stresses for seasoned lumber thicker than 4 inches are included in table 8.

Modification for Density

Strength properties may be increased by 17 percent and E by 5 percent for lumber meeting dense requirements (D 245, 5.6 and table 8). All species other than Douglas-fir and southern pine must follow the provisions of paragraph 5.6.2 of D 245.

4/ Illustrating this procedure, table 6 was prepared because the dry-green ratios (D 2555, table A1) for the modulus of elasticity of red and sugar maple were limiting.

Allowable Unit Stresses for Lumber Grades

Allowable unit stresses for lumber grades are derived from table 8 values for clear lumber by application of strength ratios (D 245, section 4 and tables 1-6) to strength properties and a quality factor to E values (D 245, 4.2.4 and table 7). Special factors are applied to F_b values to adjust for depth effect, and an additional factor may be applied where applicable for repetitive loading. Adjustments to F_t values conform to reductions recently recommended by the National Forest Products Association (6) and approved by the ALSC Board of Review.

A strength ratio (D 245, 4) is the ratio of the strength of a piece of lumber containing strength-reducing characteristics such as knots to its expected strength if it were a clear, straight-grained piece. Strength ratios for various lumber categories are given in table 9. The F_b strength ratios listed for grades of lumber in the Structural Light Framing (SLF), Light Framing (LF), Studs (S), and Structural Joists and Planks (SJ&P) categories are minimum ratios specified for these grades by the National Grading Rule as developed under PS 20-70 (7). Strength ratios for other lumber categories such as Beams and Stringers and Posts and Timbers are not covered by the National Grading Rule. The strength ratios listed for some of these categories in table 9 are arbitrarily chosen for demonstration purposes only and do not necessarily correspond to any grade description.

Table 9 also lists quality factors to be applied to modulus of elasticity values. The quality factors are related to F_b strength ratios (D 245, 4.2.4, table 7).

An example of stress-grade development comparable to the derivations outlined in tables 7 to 10 is given in D 245, 8 and table 13.

Size effect.-- F_b values are adjusted for size effect by a multiplication factor $(2/d)^{1/9}$, where d is the net surfaced depth or width (D 245, 6.3.1). For simplicity, a 11.25-inch depth adjustment factor (0.8254) is commonly applied to members 5 to 12 inches in nominal width and a 3.5-inch depth factor (0.9397) is applied to nominal widths 4 inches and less in SLF and LF categories. In this report (for demonstration only), we have assumed a 20-inch depth factor (0.7743) for grades of Beams and Stringers and Posts and Timbers for actual widths (depth) greater than 12 inches and 12-inch depth factor (0.8195) for nominal widths 12 inches and smaller.

Strength ratio factor.--Rules-writing agencies commonly combine the depth adjustment with F_b strength ratios and refer to the combination as a strength ratio factor (SRF). For consistency and simplicity a minimum SRF is applied to all sizes in a grade. Refer to appendix C for additional detail concerning SRF.

Contiguous members.--An increase in F_b of 15 percent is recommended for design consideration for contiguous members because member interaction provides greater load-carrying capacity than expected from predicted individual member performance (D 245, 7.8.1).

Lumber grades.--Allowable unit stresses for lumber grades (table 10) are obtained by application of strength ratios and other adjustments given in table 9 to clear lumber values given in table 8.

Rounding.--For publication, allowable unit stresses are rounded as per D 245, 6.1.1. Rounded values are included in table 10.

U.S. Forest Products Laboratory.

Deriving allowable properties of lumber (a practical guide for interpretation of ASTM Standards), by B. Alan Bendtsen and William L. Galligan. Madison, Wis. 31 p. (Gen. Tech. Rep. FPL 20, For. Prod. Lab., For. Serv., U.S. Dep. Ag.)

Presents a practical guide to using these ASTM Standards for individuals that may not be familiar with their application. Sample stress derivations supplement the text.

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Presents a practical guide to using these ASTM Standards for individuals that may not be familiar with their application. Sample stress derivations supplement the text.

Table 9.--Strength ratios, quality factors, and special adjustments

| Category | Grade | $F_b^{1/2/}$ | | F_t | | Strength ratios | | | Quality factor E |
|------------------------------|-----------------------|----------------|---------------------|----------------|---------------------------------|-----------------|-------|----------|---------------------|
| | | Strength ratio | Depth ^{3/} | Strength ratio | Special ^{4/} reduction | F_C | F_v | F_{CL} | |
| Structural light framing | Select structural | 67 | x | 0.9397 | 67 | 78 | 50 | 100 | 100 |
| | No. 1 | 55 | x | .9397 | 55 | 62 | 50 | 100 | 100 |
| | No. 2 | 45 | x | .9397 | 45 | 49 | 50 | 100 | 90 |
| | No. 3 | 26 | x | .9397 | 26 | 30 | 50 | 100 | 80 |
| Light framing | Construction Standard | 34 | x | .9397 | 34 | 56 | 50 | 100 | 80 |
| | Utility | 19 | x | .9397 | 19 | 46 | 50 | 100 | 80 |
| | | 9 | x | .9397 | 9 | 30 | 50 | 100 | 80 |
| Studs | Studs (2-4 in. wide) | | | .9397 | | 30 | 50 | 100 | 80 |
| | Studs (5-6 in. wide) | | 26 | x | .8937 | 0.80 | | | |
| Structural joists and planks | Select structural | 65 | x | .8254 | 65 | 1.00 | 69 | 50 | 100 |
| | No. 1 | 55 | x | .8254 | 55 | 1.00 | 62 | 50 | 100 |
| | No. 2 | 45 | x | .8254 | 45 | .80 | 52 | 50 | 100 |
| | No. 3 | 26 | x | .8254 | 26 | .80 | 33 | 50 | 100 |
| Beams and stringers | Strength ratio 86 | 86 | ^{5/} x | | 86 | NA | 90 | 50 | 100 |
| | Strength ratio 72 | 72 | x | .8195 | 72 | NA | 80 | 50 | 100 |
| | Select structural | 65 | x | .7743 | 65 | NA | 75 | 50 | 100 |
| | No. 1 | 55 | x | | 55 | NA | 62 | 50 | 100 |
| Posts and timbers | Strength ratio 86 | 86 | ^{5/} x | | 86 | NA | 90 | 50 | 100 |
| | Strength ratio 72 | 72 | x | .8195 | 72 | NA | 80 | 50 | 100 |
| | Select structural | 65 | x | .7743 | 65 | NA | 75 | 50 | 100 |
| | No. 1 | 55 | x | | 55 | NA | 62 | 50 | 100 |

1/ For multiple member use, see "Allowable Unit Stresses for Lumber Grades."

2/ The strength ratios shown are the minimum ratios specified by the Natural Grading Rule for each grade category; the depth factor reflects adjustment for maximum width. Actual practice most commonly deviates from this simplified presentation (see appendix C).

3/ These depth adjustments assume dry ALS sizes, except as noted.

4/ No adjustment required for 2- to 4-in. width. Where a factor is given, it applies to 5- and 6-in. nominal widths only. For 8-in. width, the factors are 0.90 for select structural, 0.80 for No. 1, and 0.64 for Nos. 2 and 3. For 10-in. and wider, use 0.80 for select structural, 0.60 for No. 1, and 0.48 for Nos. 2 and 3.

5/ 0.8195 applies to actual widths 12 in. and less; 0.7743 applies to actual widths 12 to 20 in.

Table 10.--Sample allowable unit stresses: Beams and stringers category; Select Structural grade; members greater than 12-inch nominal width^{1/}

| | F_b | F_t | F_c | F_v | $F_{c\perp}$ | E | |
|------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---|---------------------------|
| | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>Lb/in.²</u> | <u>1,000</u> <u>lb/in.²</u> | <u>Lb/in.²</u> |
| UNSEASONED | | | | | | | |
| Aspen | 834 | 825 | 593 | 600 | 549 | 550 | 57 55 |
| Maple | 972 | 975 | 690 | 700 | 652 | 650 | 93 95 |
| Yellow-poplar | 959 | 950 | 681 | 675 | 668 | 675 | 68 70 |
| Cottonwood | 824 | 825 | 586 | 575 | 574 | 575 | 56 55 |
| SEASONED ^{2/} | | | | | | | |
| Aspen | 834 | 825 | 593 | 600 | 604 | 600 | 57 55 |
| Maple | 972 | 975 | 690 | 700 | 718 | 725 | 93 95 |
| Yellow-poplar | 959 | 950 | 681 | 675 | 735 | 725 | 68 70 |
| Cottonwood | 824 | 825 | 586 | 575 | 632 | 625 | 56 55 |

1/ The first column for each property is unrounded. The second is rounded according to D 245, 6.1.1.

2/ D 245, 7.1.3 and 7.1.4.

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APPENDIX A--GROWING STOCK VOLUME

Timber growing stock volume data are used as weighting factors in the derivation of allowable design properties for marketing combinations consisting of two or more species. Volume data for many species are presented in D-2-5, tables 4 and 5. But timber of species other than those in the tables are used in structural applications. Volume data for additional species was obtained from Resources Evaluation, Forest Service, U.S. Department of Agriculture, by species and State where available. This information is summarized in table A-1 by four major geographic regions: North Central, Northeast, Southeast, and Midsouth. The States or portions of States in each region are as follows:

North Central -- Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, and Wisconsin.

Northeast -- Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia.

Southeast -- Florida, Georgia, North Carolina, South Carolina, and Virginia.

Midsouth -- Alabama, Arkansas, Louisiana, Mississippi, East Oklahoma, Tennessee, and East Texas.

For many of the species listed in table A-1, volume data have not yet been tabulated by Resources Evaluation in every region. Thus, for these species, total species volume estimates are not listed. Nevertheless, the data should still be useful for making combinations within a region or between two or more regions. For example, there may be interest in developing design properties for a combination of all red oaks, all white oaks, or all oaks in the Midsouth region, the Southeast region, or the two regions combined.

The volume estimates in table A-1 should not be considered official in the context of National timber inventories normally published by Resources Evaluation of the Forest Service. Although there may be small discrepancies in the data, we believe they are sufficiently accurate for use as weighting factors for developing species combinations.

These discrepancies exist because the data received from Resources Evaluation contained volume estimates for an "Other Hardwoods" category in each major region. If the volume was not tabulated for a particular species in a region, we could not be certain whether the region contained no volume for that species or whether the species was included in the "Other Hardwoods" category. However, a species included in this category is likely to be of minor importance (low volume) in the region. Also, a volume estimate may contain more than one species; e.g., "basswood" estimates may contain American and white basswood. In this case,

however, white basswood most likely does not make a significant contribution to the total basswood volume. A similar conclusion would probably also apply where other species estimates are combined.

Table A-1.--Growing stock volume for certain hardwood species by major geographic regions (million ft³)

| Species | North central | North- east | Mid- south | South- east | Total |
|--|------------------|----------------|---------------|----------------|-------|
| Ash (<i>Fraxinus</i>): | | | | | |
| Green (<i>F. pennsylvanica</i>) | <u>1/</u> - | - | 1,282 | - | - |
| White (<i>F. americana</i>) | - | - | 575 | - | - |
| Balsam poplar (<i>Populus balsamifera</i>) | 637 | - | <u>2/</u> --- | --- | - |
| Basswood (<i>Tilia</i> sp.) | 1,606 | 995 | 164 | 202 | 2,771 |
| Birch (<i>Betula</i>): | | | | | |
| Gray (<i>B. populifolia</i>) | --- | 10 | --- | --- | 10 |
| Paper (<i>B. papyrifera</i>) | 2,114 | 1,658 | --- | --- | 3,773 |
| River (<i>B. nigra</i>) | 95 | 21 | 160 | --- | 275 |
| Boxelder (<i>Acer negundo</i>) | 20 | - | 193 | 25 | - |
| Cherry (<i>Prunus</i> sp.) | 331 | 2,404 | - | 118 | - |
| Cottonwood, eastern (<i>Populus deltoides</i>) | 457 | - | 472 | 91 | - |
| Cucumber (<i>Magnolia acuminata</i>) | 1 | 125 | 49 | 81 | 256 |
| Elm (<i>Ulmus</i>): | | | | | |
| American (<i>U. americana</i>) | - | - | 884 | - | - |
| Rock (<i>U. thomasii</i>) | - | - | 4 | - | - |
| Slippery (<i>U. rubra</i>) | - | - | 161 | - | - |
| Holly (<i>Ilex opaca</i>) | --- | 3 | 118 | 68 | 189 |
| Locust: | | | | | |
| Black locust (<i>Robinia pseudoacacia</i>) | 92 | 365 | 153 | 321 | 931 |
| Honeylocust (<i>Gleditsia triacanthos</i>) | 30 | --- | 136 | 12 | 178 |

(Page 1 of 2)

Table A-1.--Growing stock volume for certain hardwood species by major geographic regions (million ft³)--Con.

| Species | North central | North- east | Mid- south | South- east | Total |
|--|------------------|----------------|---------------|----------------|-------|
| Magnolia (Magnolia): | | | | | |
| Southern (M. grandiflora) | --- | --- | 142 | 92 | 234 |
| Sweetbay (M. virginiana) | --- | --- | 672 | 606 | 1,278 |
| Oak red (Quercus sp.) | | | | | |
| Black (Q. velutina) | - | - | 2,109 | 1,458 | - |
| Cherrybark (Q. falcata var. pagodaefolia) | - | - | 1,169 | 204 | - |
| Laurel (Q. laurifolia) | - | - | 481 | 1,572 | - |
| Northern red (Q. rubra) | - | - | 1,164 | 1,842 | - |
| Pin (Q. palustris) | - | - | 50 | 40 | - |
| Scarlet (Q. coccinea) | - | - | 774 | 1,932 | - |
| Shumard (Q. shumardii) | - | - | 229 | 38 | - |
| Southern red (Q. falcata) | - | - | 3,392 | 1,400 | - |
| Willow (Q. phellos) | - | - | 1,775 | 511 | - |
| Oak, white (Quercus sp.) | | | | | |
| Bur (Q. macrocarpa) | - | - | 11 | --- | - |
| Chestnut (Q. prinus) | - | - | 1,222 | 2,677 | - |
| Chinkapin (Q. muehlenbergii) | - | - | --- | 10 | - |
| Overcup (Q. lyrata) | - | - | 975 | 179 | - |
| Post (Q. stellata) | - | - | 4,041 | 778 | - |
| Swamp chestnut (Q. michauxii) | - | - | 333 | 267 | - |
| Swamp white (Q. bicolor) | - | - | 16 | 15 | - |
| White (Q. alba) | - | - | 4,752 | 4,608 | - |
| Osage-orange (Maculra pomifera) | 1 | --- | 14 | --- | 15 |
| Sassafras (Sassafras albidum) | 48 | 30 | 114 | --- | 192 |
| Tupelo (Nyssa): | | | | | |
| Blackgum (N. sylvatica) | 282 | 442 | 2,529 | 5,400 | 8,653 |
| Water (N. aquatica) | --- | --- | 1,213 | 652 | 1,864 |
| Walnut (Juglans nigra) | 374 | 254 | - | 107 | - |

1/ - symbolizes that the volume for the species in the region is unknown.

2/ --- symbolizes that there is no significant volume for the species in the region.

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APPENDIX B--A COMPUTER PROGRAM FOR CALCULATING EXCLUSION LIMIT FOR A COMBINATION OF SPECIES

ASTM D 2555, Section 5.2.2.2 and others, require calculation of a 5 percent exclusion limit for modulus of rupture, maximum crushing strength parallel to grain, and shear by adding the areas under volume-weighted frequency distributions of each species at successively higher levels of strength until a value is obtained below which 5 percent of the area under the combined frequency distribution will fall.

This appendix presents a computer program for calculating the 5 percent exclusion limit for three mechanical properties. The program is written in Fortran V and has been executed on the Univac 1110. It should be easily adaptable to other computers.

Numerical Procedure

The frequency distribution of a mechanical property for a combination of species is, in general, a heterogeneous distribution. The numerical procedure assumes the heterogeneous distribution is made up of two or more component normal distributions, having sample estimates of the property mean and standard deviations as listed in table 1, with each component distribution weighted according to the volume estimates in that table. These normal distributions overlap one another, and a value of the property is sought such that 95 percent of the wood in the entire combination will exceed it.

The property axis of the combined frequency distribution is subdivided into a set of uniform classes of width (w). Each component normal frequency distribution is integrated from $-\infty$ to an upper class limit (\underline{x}_i) selected to be below the exclusion limit of the heterogeneous distribution. These integration results are weighted to reflect the timber volume of the species represented by each component distribution. Successive classes are then integrated, the results weighted and accumulatively summed until the summation exceeds 0.05. The last class integrated contains the 5 percent exclusion limit, which is then obtained by straightline interpolation between summations of integrations to the lower and upper limits of the last class.

For successful operation of the program, \underline{x}_i must be below the 5 percent exclusion limit of the combined distribution. Also, w must be small for accurate interpolation of the exclusion limit in the last class. Arbitrarily chosen dimensionless factors are entered as input to calculate \underline{x}_i and w as a proportion of the lowest species property average (\bar{x}) in the combination. We have found factors of 0.5 and 0.005 appropriate

for calculating x_i and w , respectively.

Additional details concerning the numerical procedures can be obtained from the Forest Products Laboratory.

Program Input

There are two kinds of card inputs: (1) Species statistics and (2) factors for calculating \bar{x}_i and w . Type (1) cards each describe one species and are limited to 50 in number. Figure B-1 is an example of a set of cards for four species and the type (2) card. A species statistics card includes estimates of the mean (\bar{x}) and standard deviation (s) for modulus of rupture, maximum crushing strength parallel to grain, and shear; a volume estimate; and any convenient species designation code.

Figure B-1. -- Sample input cards

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45

| Species designation | TYPE (1) CARDS | | | | | | | | | | | | | | | | | | | | | | | | | |
|------------------------|--------------------|---|---|----------------------|---|---|---|-------|---|---|--------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Modulus of rupture | | | Compression parallel | | | | Shear | | | Volume | | | | | | | | | | | | | | | |
| | x | s | x | x | s | x | s | x | s | x | | | | | | | | | | | | | | | | |
| 1 | 7 | 9 | 2 | 0 | 1 | 2 | 6 | 7 | 3 | 2 | 7 | 0 | 5 | 8 | 9 | 1 | 1 | 2 | 8 | 1 | 5 | 8 | 1 | 8 | 0 | 1 |
| 2 | 7 | 6 | 9 | 0 | 1 | 2 | 3 | 0 | 3 | 2 | 8 | 0 | 5 | 9 | 0 | 1 | 1 | 5 | 1 | 1 | 6 | 1 | 6 | 0 | 3 | 7 |
| 3 | 5 | 8 | 2 | 0 | 9 | 3 | 1 | | 2 | 4 | 9 | 0 | 4 | 4 | 8 | 1 | 0 | 5 | 3 | 1 | 4 | 7 | 5 | 5 | 0 | 7 |
| 4 | 9 | 4 | 2 | 0 | 1 | 5 | 0 | 7 | 4 | 0 | 2 | 0 | 7 | 2 | 4 | 1 | 4 | 6 | 5 | 2 | 0 | 5 | 8 | 5 | 6 | 6 |

TYPE (2) CARD

Initial
integration
limit
(x_1) Class
width
(w)

| | |
|----|------|
| .5 | .005 |
|----|------|

Program Output

The program output shown in table B-1 is self-explanatory.

Table B-1.--Program output

| Species | Average property | Standard deviation | Exclusion limit | Relative weight | Combined exclusion limit |
|----------------------|---------------------|-----------------------|--------------------|--------------------|--------------------------------|
| MODULUS OF RUPTURE | | | | | |
| 1 | 7920. | 1267. | 5836. | .0822 | |
| 2 | 7690. | 1230. | 5667. | .2755 | |
| 3 | 5820. | 931. | 4289. | .2513 | |
| 4 | 9420. | 1507. | 6941. | .3909 | 4963. |
| COMPRESSION PARALLEL | | | | | |
| 1 | 3270. | 589. | 2301. | .0822 | |
| 2 | 3280. | 590. | 2309. | .2755 | |
| 3 | 2490. | 448. | 1753. | .2513 | |
| 4 | 4020. | 724. | 2829. | .3909 | 2056. |
| SHEAR | | | | | |
| 1 | 1128. | 158. | 868. | .0822 | |
| 2 | 1151. | 161. | 886. | .2755 | |
| 3 | 1053. | 147. | 811. | .2513 | |
| 4 | 1465. | 205. | 1128. | .3909 | 883. |

The Program

```
C
C      A PROGRAM FOR CALCULATING PROPERTIES FOR GROUPS OF SPECIES
C
C      DIMENSION STRAT(3,999),EXC(3),JSQ(51),XBAR(51,3),STD(51,3),AVE(3),
C      .C(3,3),XM(3),VOL(51)
C      DATA ASP/.56418958/A1/.22583684/A2/-25212866/A3/1.2596951/
C      DATA A4/-1.2878224/A5/.94064607/A6/.3275911/
C
C      READ FACTORS FOR CALCULATING INITIAL X AND CLASS WIDTH VALUES,
C      FACTORS ARE MULTIPLIED BY THE LEAST AVERAGE PROPERTY OF A GROUP
C      TO ARRIVE AT THE ACTUAL VALUES. DATA CARD FORMAT IS
C      2F10., RIGHT JUSTIFIED, INCLUDE DECIMAL POINTS.
C
C      1 READ 2,XFC,WFC
C      2 FORMAT(2F10.0)
C
C      DO 4 J=1,3
C      EXC(J)=0.
C      AVE(J)=0.
C      DO 3 K=1,999
C      3 STRAT(J,K)=0.
C      4 CONTINUE
C
C      READ A GROUP OF 2-50 DATA CARDS FOLLOWED BY A TRAILER CARD
C      THAT HAS 99 PUNCHED IN CC 1-2. DATA IS RIGHT JUSTIFIED,
C      WITHOUT DECIMAL POINTS, AS FOLLOWS
C
C      COL 1-2          ANY NUMERICAL SPECIES DESIGNATION      I2
C
C      COL 3-9,16-21,27-32    SPECIES AVERAGE PROPERTIES
C
C      COL 10-15,22-26,33-37  STANDARD DEVIATION OF PROPERTIES
C                           FOR THE SPECIES
C
C      COL 38-44          TIMBER VOLUME
C
C      COL 45-80          MAY BE USED FOR REMARKS. NOT PROCESSED
C                           BY THE PROGRAM
C
C      DO 7 J=1,52
C      READ 6,JSQ(J),XBAR(J,1),STD(J,1),XBAR(J,2),STD(J,2),XBAR(J,3),
C      .STD(J,3),VOL(J)
C      6 FORMAT(I2,F7.0,F6.0,2(F6.0,F5.0),F7.0)
C      IF(JSQ(J).EQ.99)GO TO 8
C      7 CONTINUE
C
C      8 JN=J-1
C      AVOL=0.
C      DO 12 I=1,3
C      TVOL=AVOL
C      DO 10 J=1,JN
C      AVE(I)=AVE(I)+XBAR(J,I)*VOL(J)
C      10 TVOL=TVOL+VOL(J)
C      12 AVE(I)=AVE(I)/TVOL
```

```

C      DEVELOP C-ARRAY
DO 13 J=1,3
13 XM(J)=99999999.
DO 15 J=1,3
DO 15 K=1,JN
IF(XBAR(K,J).GE.XM(J))GO TO 15
XM(J)=XBAR(K,J)
15 CONTINUE
DO 17 J=1,3
C(J,1)=XM(J)*XFC
C(J,3)=XM(J)*WFC
17 C(J,2)=C(J,1)+997.*C(J,3)
PRINT 99
99 FORMAT(1H1)
DO 50 JJ=1,3
IF(AVE(JJ)),50,
DO 32 II=1,JN
N=0
L=0
Y=C(JJ,1)
20 IF(Y-C(JJ,2)),21,21
IF(N=998)22,21,22
21 L=1
22 N=N+1
X=(Y-XBAR(II,JJ))/STD(II,JJ)
XX=X
IF(X),24,24
X=-X
24 X=X/1.414214
E=1./(1.+A6*X)
X2=-X*X
Q=2.*ASP*EXP(X2)
ERR=.5*(A1*E+A2*E*E+A3*E*E*E+A4*E*E*E*E+A5*E*E*E*E)*0
IF(XX),25,25
AREA2=ERR
GO TO 26
25 AREA2=1.-ERR
26 IF(Y-C(JJ,1))30,,30
STRAT(JJ,N)=STRAT(JJ,N)+AREA2*VOL(II)
28 Y=Y+C(JJ,3)
AREA1=AREA2
GO TO 20
30 STRAT(JJ,N)=STRAT(JJ,N)+(AREA2-AREA1)*VOL(II)
IF(L-1)28
N=N+1
STRAT(JJ,N)=STRAT(JJ,N)+ERR*VOL(II)
IF(Y-C(JJ,2)),32,32
PRINT 33,JJ
33 FORMAT(' EXCLUSION LIMIT NOT REACHED FOR PROP',I2)
32 CONTINUE
DO 38 I=1,999
38 STRAT(JJ,I)=STRAT(JJ,I)/TVOL
CUM=0.
DO 46 I=1,999

```

```

IF(I=1),,42
IF(.05-STRAT(JJ,I)),,42
PRINT 40,JJ
40 FORMAT(/, ' LOWEST CLASS CONTAINS EXCLUSION LIMIT FOR PROP',I3)
GO TO 50
42 IF(STRAT(JJ,I)=.05+CUM),44,44
CUM=CUM+STRAT(JJ,I)
GO TO 46
44 STEPS=I-2
EXC(JJ)=C(JJ,1)+STEPS*C(JJ,3)+C(JJ,3)*(05-CUM)/STRAT(JJ,I)
GO TO 50
46 CONTINUE
50 CONTINUE
PRINT 99
DO 80 I=1,3
IF(AVE(I)),80,
IF(I=2),53,55
PRINT 52
52 FORMAT(' MOR')
GO TO 63
53 PRINT 56
56 FORMAT(////' COMP PAR')
GO TO 63
55 PRINT 58
58 FORMAT(////' SHEAR')
GO TO 63
63 PRINT 64
64 FORMAT(/, ' SPECIES AVE PROP STD DEV EXCL LIM REL WT COMBINED
,EXCL LIMIT',/)
JD=JN/2+1
DO 70 J=1,JN
FIVEP=XBAR(J,I)-1.645*STD(J,I)
WT=VOL(J)/TVOL
K=JSQ(J)
IF(JD.EQ.J) GO TO 66
PRINT 68,K,XBAR(J,I),STD(J,I),FIVEP,WT
GO TO 70
66 PRINT 68,K,XBAR(J,I),STD(J,I),FIVEP,WT,EXC(I)
68 FORMAT(I5,F12.0,2F9.0,F9.4,5X,F8.0)
70 CONTINUE
80 CONTINUE
PRINT 99
STOP
END

```

APPENDIX C--DEVELOPMENT OF STRENGTH RATIO FACTORS AND STRENGTH RATIOS FOR GRADING RULES

Strength Ratio Factor

Allowable design properties for structural lumber grades are derived from clear wood lumber properties through application of strength ratios (SR). Basic to this derivation is the concept of a minimum acceptable F_b SR for each lumber grade. For example, in the Structural Joists and Planks lumber category, the minimum acceptable F_b SR's for various grades are Select Structural, 65 percent; No. 1, 55 percent; No. 2, 45 percent; and No. 3, 26 percent. Grade descriptions are written which detail the maximum permissible defects, staying within limitations defined by these minimum F_b strength ratios. Strength ratios for other properties commonly are controlled by the defect limitations pertaining to F_b .

The F_b SR of a grade may exceed the minimum acceptable SR, depending upon the SR associated with critical or limiting defects in the grade description. The SR may also vary between sizes within a grade, again depending upon the limiting defect of the grade description.

For simplicity in derivation procedures and for consistency in allowable properties between sizes within a grade, a minimum F_b strength ratio factor (SRF) is commonly applied to all sizes within a grade. The SRF is the product of the SR corresponding to the limiting defect for a size and grade and the depth factor^{5/} for each size. The SRF is calculated for all sizes in a grade to determine the minimum value. An example is shown in table C-1 for No. 2 Joists and Planks:

The minimum or controlling SRF is 0.3771 (14-in. nominal width and 4-1/8 knot) which is applied to clear lumber stresses to obtain F_b for these widths of No. 2 grade. It is noted that only edge knots are shown in this sample SRF derivation for F_b because knots in other locations (centerline and narrow face knots) are less critical for this particular grade description.

^{5/} Reference (2), paragraph 6.3.1.

Strength Ratios

The SRF applies only to F_b because depth adjustment (D 245 6.3.1) is not required for other properties. Rather, a minimum SR is determined for F_t and $F_{C||}$ which is applied to all sizes in a grade. The critical defect for F_t is frequently the same as for F_b . In table C-1, however, the 4-1/8-inch edge knot in combination with depth adjustment for 14 inch width is limiting for F_b (SRF = 0.3771) while the 3-1/4-inch edge knot (10 in. width) is limiting for F_t (SR = 0.4502). Centerline knots are most commonly the critical defect in $F_{C||}$. The minimum SR for $F_{C||}$ and F_t for a grade are determined by constructing tables similar to table C-1 showing the SR's for limiting defects for all widths in the lumber category.

An SR of 50 percent is commonly assigned to F_V for most grades and sizes although higher values may be permitted depending on shake and split limitations. $F_{C|}$ is assumed to be grade independent, and a 100 percent strength ratio is assigned to all grades.

Table C-1.--Example of calculating SRF for No. 2
Joists and Planks

| Nominal width | Knot size | Knot location | SR | Depth factor | SRF |
|---------------|------------|---------------|--------|--------------|--------|
| <u>In.</u> | <u>In.</u> | | | | |
| 5 | 1-5/8 | Edge | 0.4559 | 0.9138 | 0.4166 |
| 6 | 1-7/8 | Edge | .4733 | .8937 | .4230 |
| 8 | 2-1/2 | Edge | .4662 | .8667 | .4041 |
| 10 | 3-1/4 | Edge | .4502 | .8435 | .3797 |
| 12 | 3-3/4 | Edge | .4684 | .8254 | .3866 |
| 14 | 4-1/8 | Edge | .4653 | .8105 | .3771 |

SRF for 1:8 slope of grain is $0.53 \times 0.8105 = 0.4296$.